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Effectiveness of Ethnoecological-STEM Project-Based Learning Model to Improve Critical Thinking Skills, Creativity, and Science Concept Mastery

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Abstract: Students' ability to master critical thinking skills and creativity is often found in current learning. This research aims to test the effectiveness of the Ethnoecological-Science, Technology, Engineering and Mathematics based on Project Based Learning (E-STEM PjBL) learning model in improving mastery of science concepts and critical thinking skills as well as the creativity of prospective science teachers. This model is an innovative project-based learning model integrated with Ethnoecology-STEM in the Environmental Physics course with a project on the use of water hyacinth with the following syntax: Learn, Discuss, Perform, Elaborate, Convey, Practice, Evaluate, and Use. The research method used was quasi-experimental with a one-group pretest-posttest design. The research subjects were 31 science education students at Universitas Islam Negeri Salatiga, Central Java, Indonesia. Data collection techniques use test instruments and observation sheets. The instrument was validated empirically by four experts and analyzed using Aiken's V formula. Data was analyzed using SPSS on concept mastery test data with the Paired-Sample t-test, and critical thinking skills test data with the Wilcoxon Signed Ranks Test. The average N-Gain value is obtained for each data point, while the creativity data is the average creativity of two observers. The research results showed a significant and quite effective increase in science concepts mastery, critical thinking skills, and creativity in the good and very good categories. This research concludes that the application of the E-STEM PjBL model is effective in increasing mastery of science concepts, critical thinking skills, and creativity of prospective science teachers.

Keywords: *Project-based learning, ethnoecological-stem, science concept mastery, critical thinking skills, creativity.*

Introduction

Creative thinking is the ability of students to develop and convey new ideas openly and responsively, and it can be applied in life (Yusliani et al., 2019) or a series of processes for understanding problems, making guesses, hypothesizing about problems, looking for answers, proposing evidence, and reporting results to be applied in the creation process (Birgili, 2015). Critical thinking is considered the new basis for 21st-century learning (Trilling and Fadel, 2009), while creative thinking (creativity) has also been seen as an important basis for students (Gube and Lajoie, 2020a; Ritter and Mostert, 2016; Srikongchan et al., 2021). People who think scientifically must be able to think creatively (Suratno et al., 2019). Critical thinking and creativity need to be improved because it is closely related to students' success in mastering concepts. Ulger (2018) argues that students' critical thinking and creativity styles are related to their cognitive abilities. Critical thinking skills and creativity can be achieved by updating the quality of learning, helping students develop participation, emphasizing project-based learning, encouraging collaboration and communication, increasing students' involvement and motivation, cultivating creativity and innovation in learning, using appropriate learning tools, and designing learning activities that are relevant to the real world (Fatmawati et al., 2019; Gube and Lajoie, 2020b; Jayadi et al., 2020)

Science education aims to study not only the content but also the nature of science: science as a cognitive (knowledge), epistemic (scientific practice), and social-institutional (scientific ethos or attitude)

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system (Akgun and Kaya, 2020; Dagher and Erduran, 2016). Bloom et al. (1956) stated in their theory of Bloom's taxonomy that educational goals must always refer to three domains: the cognitive domain (knowledge or thought processes), the affective domain (values or attitudes), and the psychomotor domain (skills). Education in the current century is facing an era of openness or globalization marked by progress in science and technology (Jayadi et al., 2020; Rahayu, 2017; Van Laar et al., 2017), often called 21st-century education. By the above thinking, the goal of 21st-century education is not only to prepare students to pass exams but also to foster learning in a way that can be transferred to their future personal, cultural, professional, academic, and civic lives (Tierney et al., 2022). Redhana (2019) believes that 21st-century education prepares human resources who master various skills to survive in the 21st century. 21st-century education must be oriented toward mastering 21st-century skills (Jayadi et al., 2020).

21st-century skills as a result of learning are divided into 3 (three) categories: learning and innovation skills or 21st-century 4C skills (Critical thinking, Communication, Collaboration, and Creativity) (Astuti et al., 2019; Santi et al., 2021), information and communication technology literacy skills, and life and career skills (Prayogi and Estetika, 2019; Van Laar et al., 2017). Therefore, critical thinking skills and creativity are fundamental in science learning in the 21st century (Mulyono et al., 2023) because they can be used to solve real-life problems (Amaliah et al., 2020; Budi and Ghofar, 2017).

21st-century education applies many student-centered learning models, including project-based learning (PjBL) (Redhana, 2019). The PjBL model is a teaching approach built on actual learning activities and tasks in a "constructivist" learning environment created in groups where students build their knowledge and educators are facilitators (Goodman et al., 2010). A vital characteristic of the PjBL model is that students can apply various skills to completing real and useful tasks (Bagheri et al., 2013; Malawati and Sahyar, 2016). The PjBL model can provide authentic experiences for students to develop a correct understanding of scientific processes and is recommended as an effective learning model to be applied at the tertiary level (Wurdinger and Qureshi, 2015).

Furthermore, the PjBL model can improve 21st-century 4C skills by integrating the STEM approach (Santi et al., 2021). STEM incorporates transdisciplinary learning, meaning students learn by blending actual scientific disciplines and solving problems in real contexts (Suganda et al., 2020). STEM learning in science can improve students' creativity or 21st-century skills. The STEM approach is increasingly popular and is used to measure creativity (Anindya and Wusqo, 2020), problem-solving (Ozkan and Umdu, 2020; Sun and Jeong, 2015), concept understanding (Liliawati et al., 2018; Yakman and Lee, 2012), understanding in science, technology, engineering, and arts, learning motivation, learning achievement, and critical thinking (Yakman and Lee, 2012). STEM learning can make science learning more interesting (Conradty and Bogner, 2019).

The facts in the field are that there are still problems in getting used to using the PjBL model which is integrated with STEM. This field study is an observation of 37 (thirty-seven) science teachers at Junior High Schools (SMP) in Semarang Regency regarding the use of the project-based learning model (PjBL) as the main choice in the learning process. From the observation results, data showed that there was still little use of the PjBL model as the main choice, namely only 5 teachers (13.5%), while 16 teachers (43.2%) used the discovery learning model and the other 16 teachers (43.2%) used the problem-based learning (PBL). The application of STEM integration in science learning, which is a combination of various scientific disciplines, is also still low, namely only 24.3% answered often, while the majority answered rarely as much as 54.1%, and some never applied as much as 21.6%. Therefore, it is necessary to prepare science education students at the tertiary level as prospective science teachers to be familiar with and skilled in using the STEM-integrated PjBL learning model.

This research focuses on developing a learning model described by Jayadi et al. (2020). The model innovation developed integrates the project-based learning (PjBL) model and Ethnoecological-STEM (Etno-STEM), named the E-STEM PjBL model. The Ethno-STEM approach can be interpreted as building scientific concepts through local wisdom and integrating them with STEM (Sartika et al., 2022)

Needs analysis, expert validation, and limited trials related to developing the E-STEM PjBL model were conducted. The results of the needs analysis produced the following novelty in this research: the syntax of the E-STEM PjBL model (Learn, Discuss, Do, Elaborate, Convey, Practice, Evaluate, and Use), the E-STEM PjBL Learning Module, and instruments to measure 21st-century skills (critical thinking and creativity).

Based on this background, this study is the result of a wide-scale trial of the E-STEM PjBL model with the syntax of Learn, Discuss, Do, Elaborate, Convey, Practice, Evaluate, and Use in Environmental Physics lectures for science education students at Salatiga State Islamic University in the 2022/2023 academic year. The trial aims to test the effectiveness of the E-STEM PjBL learning model in improving mastery of science concepts and critical thinking skills and creativity of prospective science teachers. The results of the trial in this study are expected to contribute to science education, namely the syntax of E-STEM PjBL can also be used as an alternative learning model in other project-based science courses (physics, chemistry, biology).

Materials and Methods

Research Design

This research used a quasi-experimental research method (Creswell and Creswell, 2018; Leavy, 2017) with a one-group pretest-posttest design in a class of students in the Science Education study program, totaling 31 students for a large-scale trial and 13 students for a limited-scale trial. The large-scale trial, involved 2 science lecturers as proof-readers and observers, namely the researcher and a science lecturer who was willing to be a proof-reader and observer, while on a limited-scale, it was carried out by researchers. This one-group pretest-posttest design was used to investigate the effectiveness of the E-STEM PjBL model to improve science concept mastery and critical thinking skills, while students' creativity skills were carried out through observation sheets.

Research Procedure

The research was carried out by following the syntax of the development model, namely Learn, Discuss, Perform, Elaborate, Convey, Practice, Evaluate and Use. The syntax of this model is derived from the PjBL syntax according to The George Lucas Educational Foundation (2005) and the PjBL-STEAM learning syntax according to Laboy-Rush (2010). The combined syntax can be reviewed in Table 1.

Table 1. *Syntax Formulation of E-STEAM PjBL*

Stages	PjBL (Lucas)	PjBL-STEAM (Laboy-Rush)	Syntax PjBL E-STEAM (researchers)
First	Start with the essential question	Reflection (providing a problem and inspiration to begin investigation)	Learn (study the given problem and ask challenging questions)
Second	Design a plan for the project	Research (starting research/ finding relevant sources of information)	Discuss (discuss the topic, design, and project schedule)
Third	Create a schedule	Discovery (solving a problem through a project)	Perform (carry out the project according to the agreed design and schedule)
Fourth	Monitor the students and the progress of the project	Application (applying concepts to the project and testing the project)	Elaborate (elaborate the application of concepts to the project, bring out creativity with communication and collaboration)
Fifth	Assess the outcome	Communication (project presentation/feedback)	Convey (present the results of project implementation)
Sixth	Evaluate the experience		Practice (demonstrate the results of the project in accordance with work procedures)
Seventh			Evaluate (evaluate the results and experience of carrying out the project)
Eighth			Use (implement the project in life)

The research begined with an explanation of the model and research objectives, then students were given a pre-test on mastery of science concepts and critical thinking skills. The research continued with the implementation of the learning model by the E-STEM PjBL syntax and each student was given a learning module. Classes are held in a hybrid manner, namely offline and online via Google Classroom. Online is only used for collecting project results, project-making videos, and student worksheets.

Research Instrument

The results of the needs analysis related to the development of the E-STEM PjBL model produced the E-STEM PjBL model syntax (i.e., Learn, Discuss, Peform, Elaborate, Convey, Practice, Evaluate and Use), E-STEM PjBL learning modules, and instruments to measure science concept mastery, 21st-century skills, including critical thinking and creativity. Learning tools in model books and learning modules were designed based on theory through literature review and field studies and were presented at the 2023 International Conference on Science, Education, and Technology (ISET) at Universitas Negeri Semarang (Rohman et al., 2023). Several instruments were developed to test this model's effectiveness, including expert validation sheets, science concept mastery test sheets, critical thinking skills test sheets, and creativity skills observation sheets.

Sample and Data Collection

The research was conducted on final students of the Science Education study program at Universitas Islam Negeri Salatiga, Central Java, Indonesia for the 2022/2023 academic year for 1 semester or 6 months. The first half of the semester (first 3 months) was used for limited trials with 13 students by making small classes, and then the final half of the semester (last 3 months) was used for trials in learning in 31 students for regular classes. Data collection techniques using test instruments and observation sheets. The instrument was validated empirically by four experts and analyzed using Aiken's V formula. Data on science concept mastery was taken using a description test, data on critical thinking skills used a multiple-choice test equipped with reasons, and data on creativity used an observation sheet.

Analyzing of Data

Research data was analyzed using Excel and SPSS programs. Data from expert validation was analyzed using the Aiken's V (Eq.1) formula using the Excel program. Aiken's V formula (Aiken, 1985) used as follows:

$$V = \frac{\sum s}{n(c-1)} \tag{1}$$

Description:
V = validity value
s = r-lo
r = expert's preferred category score
lo = lowest assessment score
n = number of experts
c = highest assessment score

Most of the research data was analyzed using the SPSS program, including validity and reliability, descriptive analysis, normality test, independent sample t-test, and non-parametric tests Wilcoxon. Test normality using the Shapiro-Wilk test because the sample data is only 31 students or less than 100 people. If the data is normally distributed, a parametric test is carried out, whereas if it is not normally distributed, the data is analyzed using a non-parametric test. All values obtained are interpreted at a significance level of 0.05. To answer the research objectives, pre-test and post-test data on mastery of science concepts and critical thinking skills were analyzed using the N-gain test (Hake, 1998) and N-gain percentage (Hake, 1998) as in Table 2 and Table 3, namely to determine the effectiveness of implementing the E-STEM PjBL model. The creativity skills data were analyzed for validity and reliability and the average assessment from 2 observers was interpreted using the creativity skills assessment criteria.

Table 2. *N-gain Achievement Level Criteria (<g>)*

Average <g> value	Criteria
<g> < 0,3	Low
0,3 < <g> ≤ 0,7	Moderate
0,7 ≥ <g>	High

Table 2 reveals the criteria for assessing creativity skills. When the g-value is less than 0.3, the criterion is low. Then, if the g-value is between more than 0.3 to less than equal to 0.7 then the criterion is medium. Next, if the g value is more than equal to 7 then the g value is high.

Table 3. *Criteria for N-gain Effectiveness Levels*

N-Gain (%)	Criteria
< 40	Ineffective
40 - 55	Less effective
56 - 75	Effective enough
> 75	Effective

From Table 3, it can be seen that when the percentage of the N Gain value is less than 40 %, the criterion is ineffective. Furthermore, when the N Gain percentage is at 40-55 % then it can be categorised as less effective. When the value of 56-75 can be said to be quite effective and if the value is less than 75 then the category is effective.

Results

Effectiveness of the E-STEM PjBL Model in Improving Science Concept Mastery

Science concept mastery is increased by applying the E-STEM PjBL model. Students' initial knowledge is measured through a pre-test. On the other hand, students' final science concept mastery after learning with the E-STEM PjBL model syntax is measured through a post-test. The science concept mastery test was first given to a limited class of 13 randomly selected students. The pre-test and post-test results were tested for normality using the Shapiro-Wilk test, with the Ho testing criteria (distribution of data does not deviate from the normal distribution). Ho is rejected if the sig value ≤ α 0.05, or data is normally distributed if the sig value > α 0.05. The results of the Shapiro-Wilk normality test obtained a pre-test significance value of 0.776 and a post-test of 0.083 (Table 6), all >α 0.05 so that Ho was accepted or the pre-test and post-test data were normally distributed. The aim of testing it in this limited class is to get input regarding the validity and reliability of the questions. The results of the analysis using SPSS obtained questions at a very reliable level with a Cronbach's Alpha value of 0.893 and obtained 12 valid questions. Three questions were invalid because the difficulty level was high and included questions with different strengths from the poor question category (less than 0,2). Invalid questions were not used because the subject matter of the questions still contained representative indicators. Another reason was the sequential research time.

Table 4. *Normality Test Results and Reliability Statistics for Limited Class Science Concept Mastery*

Data	Shapiro-Wilk test		Cronbach's Alpha
Pre-test	Sig.(2-tailed) 0,776>0,05	Data is normally distributed	0,893 >0,80 – 1,00 Data is Very Reliable
Post-test	Sig.(2-tailed) 0,083>0,05	Data is normally distributed	

The 12 test questions were then tested in a larger class with 31 students. The pre-test and post-test results on the large-scale test were also tested for normality using the Shapiro-Wilk test. The results of the Shapiro-Wilk normality test (Table 5) obtained a pre-test significance value of 0.122 and a post-test of 0.186, all greater than α 0.05 so that Ho was accepted or the pre-test and post-test data were normally distributed. The data met the requirements for analysis using parametric statistics. The next stage of statistical testing is the paired sample t-test, which determines the significance of increasing students' science concept mastery. The criterion used is if the t-test has a sig value < α 0.05, then Ho is rejected, and H1 is accepted (Ho = there is no difference in concept mastery scores before and after the E-STEM PjBL learning model is applied and H1 = there is a difference in concept mastery scores before and after

the E-STEM PjBL learning model is applied). Based on the t-test results, the sig value is 0.000, which means it is smaller than α 0.05, then Ho is rejected, and H1 is accepted. It means there is a significant increase in concept mastery of prospective science teachers in Environmental Physics material.

Table 5. *Results of Normality Test, Paired Sample T-test, and N-Gain Score for Science Concept Mastery in Experimental Class*

Data	Shapiro-Wilk Test		Paired-Sample T-Test		N-Gain score	Conclusion
Pre-test	Sig.(2-tailed) 0,122>0,05	Data is normally distributed	Sig. (2-tailed) 0,000<0,05	Both data are correlated	0,5809	Modium Achievement
Post-tets	Sig.(2-tailed) 0,186>0,05	Data is normally distributed	Sig. (2-tailed) 0,000<0,05	There is a significant difference.	58,09%	The upgrade is quite effective

The N-Gain test results obtained an average of 0.58 or 58.1% using the criteria in Tables 2 and 3. The effectiveness of the E- STEM PjBL model on concept mastery is in the medium category and is quite effective in increasing science concept mastery.

Effectiveness of the E- STEM PjBL Model in Improving Critical Thinking Skills

The increase in students' critical thinking skills due to implementing the E-STEM PjBL model is measured through pre-test and post-test. The results of the pre-test and post-test were tested for normality using the Shapiro-Wilk test (because the data is less than 100), with the Ho testing criteria (distribution of data does not deviate from the normal distribution), namely, Ho is rejected if the sig value ≤ α 0.05 or data normally distributed if the sig value. > α 0.05. The results of the Shapiro-Wilk normality test (Table 6) obtained a pre-test significance value of 0.369, greater than α 0.05 (normally distributed pre-test data), and a post-test of 0.006 smaller than α 0.05 (post-test data not normally distributed). The data does not meet the requirements for analysis using a parametric test, so a non-parametric test will be carried out using the Wilcoxon signed ranks test.

Table 6. *Results of Normality Test, Paired Sample T-test, and N-Gain Score for Critical Thinking Skills in Experimental Class*

Data	Shapiro-Wilk Test		Wilcoxon Signed Ranks Test			N-Gain score	Conclusion
Pre-test	Sig.(2-tailed) 0,369>0,05	Data is normally distributed	Asymp. Sig. (2-tailed) ,000<0,05	Both data are orrelated	Mean Rank: Positive Ranks 16	0,6091	Moderate Achievement
Post-tets	Sig.(2-tailed) 0,006<0,05	Data is not normally distributed	Asymp. Sig. (2-tailed) ,000<0,05	There is a ignificant ifference.		60,91%	The upgrade is quite effective.

Table 6 shows that the mean is a positive rank with an average of 16, meaning an increase between the pre-test and post-test results. The Wilcoxon Test can prove this with Asymp Sig < α 0.05 criteria, Ho is rejected, and H1 is accepted (Ho = there is no difference in the value of critical thinking skills before and after implementing the E-STEM PjBL learning model and H1 = there is a difference in the value of thinking skills critical before and after implementing the E-STEM PjBL learning model). Based on Wilcoxon Test results, the Asymp Sig value of 0.000 is obtained, which means it is smaller than α 0.05, so Ho is rejected, and H1 is accepted. The conclusion is that there is a significant increase in the critical thinking skills of prospective science teachers in Environmental Physics material. The N-Gain test results obtained an average of 0.60 or 60.91% (Table 6) using the criteria in Table 2 and 3. The effectiveness of the E-STEM PjBL model on critical thinking skills is in the medium category, and it is quite effective in improving the critical thinking skills of prospective science teachers. The post-test results are also interpreted according to assessing critical thinking skills, as in Table 7.

Table 7. *Post-test results of Critical Thinking Skills According to Observation Aspect*

Observation Aspect	Percentage of Total Critical Thinking Skills Score
Give a simple explanation	72,28 %
Build basic skills	70,56%
Make conclusions	56,45%
Make further explanations	59,68%
Organize strategies and techniques	64,31%

According to observation aspect, Table 7 conveys that students mostly master the aspect of providing simple explanations with total critical thinking skills 72,28 %. Then, in sequence, they build basic skills, organize strategies and techniques, make further explanations, and conclude.

Effectiveness of the E-STEM PjBL model in Improving Creativity

Creativity skills refer to thinking creatively, working, and creating innovations (Trilling and Fadel, 2009). The results of the assessment of creativity by two observers for 31 students in four aspects are shown in Table 8.

Table 8. *Observation Results of Creativity*

Variable	Observer 1	Observer 2	Average	Category
Fluency of thinking	3.18	3.19	3.19	Good
Flexibility	3.17	3.18	3.18	Good
Elaboration	3.30	3.28	3.29	Very good
Originality	3.15	3.18	3.17	Good

Table 8 shows that the students' fluency in the thinking aspect is 3.19, meaning that the effectiveness of implementing the E- STEM PjBL model in improving the creativity fluency skills of prospective science teachers is in the good category. Increasing the flexibility of creativity obtained a score of 3.18 or a good category. The aspect of increasing elaboration in creativity obtained a score of 3.29 or a very good category. The aspect of increasing originality in creativity obtained a score of 3.18 or a good category. The conclusion that can be drawn is that the effectiveness of implementing the E- STEM PjBL model in improving creativity skills or creativity, in general, is in a good category.

Discussions

Based on the research results, innovation in developing a learning model that integrates the project-based learning model (PjBL) with the disciplines of Ethnoecology and STEM (E-STEM PjBL model) has been proven to make a positive and significant contribution to the learning success of prospective science teachers. This can be seen from the assessment results of science concept mastery, which show a significant increase. Applying the E-STEM PjBL model has proven effective in increasing science concept mastery. Students master science concepts not only through reading the material in the module but also through the experience gained while carrying out the project. While carrying out the project, students will also develop scientific attitudes due to the scientific methods that students apply when working on the project. The findings in this research are from previous research, which confirms that project-based learning can increase mastery of concepts (Hanif et al., 2019; Yamin et al., 2017) and problem solving ability (Andanawarih et al., 2019)

can cultivate high-level thinking in implementing scientific learning (observing, associating, trying, discussing, and communicating) (Santi et al., 2020). This shows that the E-STEM PjBL model is in line with the nature of science: science as a cognitive, epistemic (scientific method), and social-institutional (scientific attitude) system (Akgun and Kaya, 2020; Erduran and Dagher, 2014). This model is also in line with (Bloom et al., 1956), who stated in Bloom's taxonomy that educational goals must always refer to three domains: the cognitive domain (knowledge or thought processes), the affective domain (values or attitudes), and the psychomotor domain (skills).

It is also line with the objective of this research to reveal the effectiveness of the E- STEM PjBL model in improving the critical thinking skills of prospective science teachers. The critical thinking skills studied include five aspects: 1) providing simple explanations, 2) building basic skills, 3) concluding, 4) making further explanations, and 5) organizing strategies and techniques (Ennis, 2013). Based on the results of the pre-test and post-test, there are significant differences, meaning that applying the E- STEM PjBL model in learning has proven effective in improving critical thinking skills. Then, in sequence, they build basic skills, organize strategies and techniques, make further explanations, and conclude. The application of the PjBL model makes an excellent contribution to increasing scientific literacy, critical thinking abilities (Muhibbuddin et al., 2020), and other essential skills, such as collaboration, communication, creativity, and critical thinking (Allison, 2018; Samsudi et al., 2019). STEM can develop critical thinking in real-world problems, make science learning easier to increase students' motivation (Miller and Dumford, 2016), and quality human resources (Anwar et al., 2023).

Applying the Etnoecological-STEM PjBL model with the project of utilizing water hyacinth plants, besides increasing science concept mastery and critical thinking skills, is also expected to increase students' creativity through critical thinking skills.

Figure 1. *Water hyacinth plants*

The research results show that the application of the E-STEM PjBL model is effective in the good category in improving the creativity of prospective science teachers. Creativity can be seen in four aspects: fluency of thinking, flexibility of thinking, elaboration, and originality (Guilford, 1956). The elaboration aspect is a skill that students very well master, while fluency of thinking, flexibility, and originality are also mastered by many students. This is in line with the characteristics of the E-STEM PjBL model, which can be seen in its syntax: learn, discuss, do, elaborate, convey, practice, evaluate, and use.

The aspect of fluency of thinking will be widely trained and needed in steps 1 and 2: students study science concepts, find ideas, and discuss the findings in group discussions. The flexibility aspect is mostly trained in steps 3 and 5 when implementing projects according to the schedule and project design and in delivering project results. The elaboration aspect is mostly trained in steps 4 and 6, namely when elaborating during the project creation process and practicing the final results of project work. Aspects of originality are often trained in steps 7 and 8, because in the evaluation stage and using projects in everyday life, students must be able to argue, answer, and present them to others. This research results align with (Sumarni and Kadarwati, 2020), who stated that the Etno-STEM project-based learning model can improve critical thinking and creativity. Therefore, the PjBL model can improve creative and critical thinking skills (Allison, 2018; Samsudi et al., 2019). STEM education can foster problem-solving skills (Yuliari and Hanim, 2020) and creativity skills (Buinicontro, 2018).

Conclusions

The research concludes that the innovative E-STEM PjBL model implemented in the Environmental Physics course has been proven to improve students' science concept mastery, critical thinking skills, and creativity through creativity. Science concept mastery is obtained through material in modules, internet

media, and when elaborating science concepts in project work. Students' critical thinking skills and creativity, seen in several aspects, have been covered at every step in the syntax of the E- STEM PjBL model (learn, discuss, do, elaborate, convey, practice, evaluate, and use). Students' creativity can also be seen while working on projects or products, starting from arranging schedules, designing, working on, and demonstrating projects.

The integration of the PjBL model with the disciplines of Ethnoecology and STEM education allows for accompanying impacts on learning. Ethnoecology integration can foster an environmentally caring character, while STEM education can improve students' ability to utilize technological advances in learning. For prospective science teachers, it is essential to master science concepts and be skilled in scientific methods that require critical thinking skills and creativity, so prospective science teachers will ultimately develop scientific attitudes.

The syntax from the innovation in the E-STEM PjBL model can be applied to environmental physics and other science courses with the potential for projects that students can carry out, for example basic physics, mechanics, or biology or chemistry courses. Then, this paper is expected to be used to train student teachers in practicing other 21st century skills such as communication, collaboration, and environmental awareness.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

Conceptualization, M.H.R., S.E.N. and P.M.; methodology, S.E.N. and S.; formal analysis, S.E.N.; writing—original draft preparation, M.H.R.; writing—review and editing, S.E.N., S. and M.H.R.; supervision, P.M. All authors have read and agreed to the published version of the manuscript.

References

Akgun, S., & Kaya, E. (2020). How Do University Students Perceive the Nature of Science? *Science & Education*, *29*(2), 299–330. https://doi.org/10.1007/s11191-020-00105-x

Allison, J. M. (2018). *Project based learning to promote 21st century skills: An action research study* [William & Mary.]. http://dx.doi.org/10.25774/w4-m5xm-wc95

Amaliah, N., Ningsih, F., Indriwati, S. E., & Gofur, A. (2020). Peningkatan Keterampilan Berpikir Kritis Mahasiswa Melalui Penerapan Model Pembelajaran Learning Cycle 7e Berbasis Lesson Study [Improving Students' Critical Thinking Skills Through the Implementation of the Lesson Study-Based Learning Cycle 7e Learning M. *BIOMA: Jurnal Biologi Dan Pembelajarannya, 2*(1), 29–36. https://ojs.unsulbar.ac.id/index.php/bioma/article/view/740

Andanawarih, M., Diana, S., & Amprasto, A. (2019). The implementation of authentic assessment through project-based learning to improve student's problem solving ability and concept mastery of environmental pollution topic. *Journal of Physics: Conference Series*, *1157*(2), 1–6. https://doi.org/10.1088/1742-6596/1157/2/022116

Anindya, F. A. U., & Wusqo, I. U. (2020). The Influence of PjBL-STEAM model toward students' problem-solving skills on light and optical instruments topic. *J. Phys.: Conf. Ser. 1567 042054*, 1–4. https://doi.org/10.1088/1742-6596/1567/4/042054

Anwar, P. I., Usmeldi, & Asrizal. (2023). Effects of STEM Integration in Science Learning on Critical Thinking and Creative Thinking Skills: A Meta-Analysis. *Jurnal Penelitian Pembelajaran Fisika*, *9*(2), 231–242. https://doi.org/10.24036/jppf.v9i2.122493

Astuti, A. P., Aziz, A., Sumarti, S. S., & Bharati, D. A. L. (2019). Preparing 21st Century Teachers: Implementation of 4C Character's Pre-Service Teacher through Teaching Practice. : Conference Series. *Journal of Physics*, *1233*(1). https://doi.org/10.1088/1742-6596/1233/1/012109

Bagheri, M., Ali, W. Z. W., Chong, M. B. A., & Daud, S. M. (2013).). Effects of Project-Based Learning Strategy on Self-Directed Learning Skills of Educational Technology Students. *Contemporary Educational Technology*, *4*(1), 15–29. https://files.eric.ed.gov/fulltext/EJ1105523.pdf

Birgili, B. (2015). Creative and Critical Thinking Skills in Problem-based Learning Environments. *2022*, *2*(2), 71–80. https://dergipark.org.tr/en/pub/jgedc/issue/38680/449365

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I Cognitive Domain*. Longmans, Green and Co. https://eclass.uoa.gr/modules/document/file.php/PPP242/Benjamin S. Bloom - Taxonomy of Educational Objectives%2C Handbook 1_ Cognitive Domain-Addison Wesley Publishing Company %281956%29.pdf

Budi, M. I., & Ghofar, C. A. (2017). Analisis Keterampilan Berpikir Kritis Dan Metakognitif Mahasiswa Program Studi Pendidikan Biologi [Analysis of Critical Thinking and Metacognitive Skills of Biology Education Study Program Students]. *Bioma: Jurnal Ilmiah Biologi*, *6*(1). https://doi.org/10.26877/bioma.v6i1.1472

Buinicontro, J. K. (2018). Gathering STE(A)M: Policy, curricular, and programmatic developments in arts-based science, technology, engeneering, and mathematics education: Introduction to special issue of art education policy Review: STEAM focus. *Art Education Policy Review Journal*, *119*(2). https://doi.org/10.1080/10632913.2017.1407979

Conradty, C., & Bogner, F. X. (2019). From STEM to STEAM: Cracking the Code? How Creativity & Motivation Interacts with Inquiry-based Learning. *Creat. Res. J.*, *31*, 1–13. https://doi.org/10.1080/10400419.2019.1641678

Creswell, J. W., & Creswell, J. D. (2018). *Research design: qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Dagher, Z. R., & Erduran, S. (2016). Reconceptualizing the Nature of Science for Science Education. *Science & Education*, *25*(1-2), 147–164. https://doi.org/10.1007/s11191-015-9800-8

Ennis, R. H. (2013). *The Nature of Critical Thinking: Outlines of General Critical Thinking Dispositions and Abilities*. University of Illinois.

Erduran, S., & Dagher, Z. R. (2014). Reconceptualizing Nature of Science for Science Education. *Contemporary Trends and Issues in Science Education*, 1–18.

Fatmawati, A., Zubaidah, S., Mahanal, S., & Sutopo. (2019). Critical Thinking, Creative Thinking, and Learning Achievement: How They are Related. *Journal of Physics: Conference Series*, *1417*(012070), 1–9. https://doi.org/10.1088/1742-6596/1417/1/012070

Goodman, B., Stivers, J., & Fall. (2010). Project - Based Learning. *Educational Psychology*, *ESPY 505*. https://www.fsmilitary.org/pdf/Project_Based_Learning.pdf

Gube, M., & Lajoie, S. (2020a). Adaptive expertise and creative thinking: A synthetic review and implications for practice. *Thinking Skills and Creativity*, *35*(100630), 1–14. https://doi.org/10.1016/j.tsc.2020.100630

Gube, M., & Lajoie, S. (2020b). Adaptive expertise and creative thinking: A synthetic review and implications for practice. *Thinking Skills and Creativity*, *35*(10), 1–14. https://doi.org/https://doi.org/10.1016/j.tsc.2020.100630

Guilford, J. . (1956). The Structure of Intellect. *Psychological Bulletin*, *53*(4), 267–293. https://doi.org/10.1037/h0040755

Hake, R. R. (1998). Interactive-Engagement vs. Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*, *66*(64). http://dx.doi.org/10.1119/1.18809

Hake, R. R. (2002). Relationship of individual student normalized learning gains in mechanics with gender, high-school physics, and pretest scores on mathematics and spatial visualization. *The Physics Education Research Conference*. http://www.physics.indiana.edu/~hake

Hamid, A. (2017). Analysis of Students' Critical and Creative Thinking Style and Cognitive Ability on Chemistry. *Advances in Social Science, Education and Humanities Research*, *100*, 302–304. https://doi.org/10.2991/seadric-17.2017.64

Hanif, S., Wijaya, A. F. C., Winarno, N., & Salsabila, E. R. (2019). The use of STEM project-based learning toward students' concept mastery in learning light and optics. *Journal of Physics: Conference Series*, *1280*(3), 1–8. https://doi.org/10.1088/1742-6596/1280/3/032051

Jayadi, A., Putri, D. H., & Johan, H. (2020). Identifikasi Pembekalan Keterampilan Abad 21 pada Aspek Keterampilan Pemecahan Masalah Siswa SMA Kota Bengkulu dalam Mata Pelajaran Fisika. *Jurnal Kumparan Fisika*, *3*(1), 25–32. https://doi.org/10.33369/jkf.3.1.25-32

Leavy, P. (2017). *Research Design*. The Guilford Press.

Liliawati, W., Rusnayati, H., Purwanto, & Aristantia, G. (2018). Implementation of STEAM Education to Improve Mastery Concept. *IOP Conf. Series: Materials Science and Engineering 288*, 1–6. https://iopscience.iop.org/article/10.1088/1757-899X/288/1/012148

Malawati, R., & Sahyar. (2016). Peningkatan Keterampilan Proses Sains Mahasiswa dengan Model Project Based Learning Berbasis Pelatihan dalam Pembelajaran Fisika [Improving Students' Science Process Skills with a Project Based Learning Model Based on Training in Physics Learning]. *Jurnal Pendidikan Fisika*, *5*(1), 58–63. http://jurnal.unimed.ac.id/2012/index.php/jpf

Miller, A. L., & Dumford, A. D. (2016). Creative cognitive processes in higher education. *The Journal of Creative Behavior*, *50*(4), 282–293. https://doi.org/10.1002/jocb.2016.50.issue-4

Muhibbuddin, Yustina, N., & Safrida. (2020). Implementation of project-based learning (pjbl) model in growth and development learning to increase the students' science literacy and critical thinking skills. *IJAEDU- International E-Journal of Advances in Education*, *6*(16), 66–72. http://ijaedu.ocerintjournals.org/en/pub/issue/56446/788256

Mulyono, Y., Suranto., Yamtinah, S., & Sarwanto. (2023). Development of critical thinking skills and creativity instruments based on environmental socio-scientific issues. *International Journal of Instruction*, *16*(3), 691–710. https://doi.org/10.29333/iji.2023.16337a

Ozkan, G., & Umdu, T. U. (2020). Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics. *Research in Science and Technological Education*, 1–21. https://doi.org/10.1080/02635143.2020.1769586

Prayogi, D. R., & Estetika, R. (2019). Kecakapan Abad ke-21: Kompetensi Digital Pendidik Masa Depan [21st Century Skills: Digital Competencies of Future Educators]. *Jurnal Manajemen Pendidikan*, *14*(2), 144–151. https://doi.org/10.23917/jmp.v14i2.9486

Rahayu, S. (2017). Technological Pedagogical Content Knowledge (TPACK): Integrasi ICT dalam Pembelajaran IPA Abad 21 [Technological Pedagogical Content Knowledge (TPACK): Integration of ICT in 21st Century Science Learning]. *TPACK: Optimalisasi Pemanfaatan ICT Untuk Meningkatkan Profesionalisme Guru Dalam Pembelajaran IPA Di Era Digital*, 1–14. https://www.researchgate.net/profile/Sri-Rahayu-16/publication/331986261_Technological_Pedagogical_Content_Knowledge_TPACK_Integrasi_ICT_dalam_Pembelajaran_IPA_Abad_21/links/5e5852264585152ce8f4aa1b/Technological-Pedagogical-Content-Knowledge-TPACK-Integr

Redhana, I. W. (2019). Mengembangkan Keterampilan Abad ke-21 dalam Pembelajaran Kimia [Developing 21st Century Skills in Chemistry Learning]. *Jurnal Inovasi Pendidikan Kimia*, *13*(1), 2239–2253. https://journal.unnes.ac.id/nju/index.php/JIPK/article/view/17824/8934

Ritter, S. M., & Mostert, N. (2016). Enhancement of Creative Thinking Skills Using a Cognitive-Based Creativity Training. *Journal of Cognitive Enhancement*, *1*(3), 243–253. https://doi.org/10.1007/s41465-016-0002-3

Rohman, M. H., Marwoto, P., & Priatmoko, S. (2023). The Needs Analysis for the Development of an Ethnoecological-STEAM Project-Based Learning Model with the Utilization of Water Hyacinth to Improve 21st Century 4C Skills for Students as Science Teacher Candidates. *International Conference on Science, Education and Technology*, 427–437. https://proceeding.unnes.ac.id/index.php/ISET/article/view/2455

Samsudi, Supraptono, E., Sunyoto, & Rohman, S. (2019). The implementation of project-based learning in productive skill programs for the development of 21st century vocational school students. *UNNES International Conference on Research Innovation and Commercialization*, 470–479. https://doi.org/10.18502/kss.v3i18.4738

Santi, K., Sholeh, S. M., Irwandani, Alatas, F., Rahmayanti, H., Ichsan, I. Z., & M.M., R. (2021). STEAM in environment and science education: Analysis and bibliometric mapping of the research literature (2013-2020). *Journal of Physics: Conference Series 1796*, 1–11. https://doi.org/10.1088/1742-6596/1796/1/012097

Sartika, S. ., Efendi, N., & Wulandari, F. E. (2022). Efektivitas Pembelajaran IPA Berbasis Etno-STEM dalam Melatihkan Keterampilan Berpikir Analisis [The Effectiveness of Ethno-STEM Based Science Learning in Practicing Analytical Thinking Skills]. *Jurnal Dimensi Pendidikan Dan Pembelajaran*, *10*(1), 1–9. https://doi.org/10.24269/dpp.v10i1.4758

Srikongchan, W., Kaewkuekool, S., & Mejaleurn, S. (2021). Backward Instructional Design based Learning Activities to Developing Students' Creative Thinking with Lateral Thinking Technique. *International Journal of Instruction*, *14*(2), 233–252. https://doi.org/10.29333/iji.2021.14214a

Suganda, E., Latifah, S., Irwandani, Sari, P. M., Rahmayanti, H., Ichsan, I. Z., & M.M, R. (2020). STEAM and Environment on students' creative-thinking skills: A meta-analysis study. *Journal of Physics: Conference Series 1796*, 1–11. https://doi.org/10.1088/1742-6596/1796/1/012101

Sumarni, W., & Kadarwati, S. (2020). Ethno-STEM project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia (JPII)*, *9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754

Sun, S., & Jeong, K. (2015). The Effect of a Climate Change Monitoring Program on Students' Knowledge and Perceptions of STEAM Education in Korea. *Eurasia Journal of Mathematics Science and Technology Education*, *11*(6), 1321–1338. https://doi.org/https://doi.org/10.12973/eurasia.2015.1390a

Suratno, Komaria, N., Yushardi, Dafik, & Wicaksono, I. (2019). The effect of using synectics model on creative thinking and metacognition skills of junior high school students. *International Journal of Instruction*, *12*(3), 133–150. https://files.eric.ed.gov/fulltext/EJ1220194.pdf

Tierney, G., Urban, R., Olabuenaga, G., & Paulger, C. (2022). Designing Project-Based Learning Curricula: Leveraging curriculum development for deeper and more equitable learning. *Lucas Education Research*. https://www.lucasedresearch.org/wp-content/uploads/2022/05/Designing-PBL-Curricula_22.pdf

Trilling, B., & Fadel, C. (2009). *21st Century Skills: Learning for Life in Our Times*. John Wiley & Sons.

Ulger, K. (2018). The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education. *Interdisciplinary Journal of Problem-Based Learning*, *12*(1), 3–6. https://doi.org/10.7771/15415015.1649

Van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, *72*, 577–588. https://doi.org/https://doi.org/10.1016/j.chb.2017.03.010

Wurdinger, S., & Qureshi, M. (2015). Enhancing College Students' Life Skills through Project Based Learning. *Innovative Higher Education*, *40*(3), 279–286. https://doi.org/10.1007/s10755-014-9314-3

Yakman, G., & Lee, H. (2012). Exploring the Exemplary STEAM Education in the U.S. as a Practical Educational Framework for Korea. *Journal of The Korean Association for Science Education*, *32*(6), 1–5. https://doi.org/10.14697/jkase.2012.32.6.1072

Yamin, Y., Permanasari, A., Redjeki, S., & Sopandi, W. (2017). Application of model project based learning on integrated science in water pollution. *Journal of Physics: Conference Series 895*, *12153*, 1–8. https://doi.org/10.1088/1742-6596/895/1/012153

Yuliari, N. K. R., & Hanim, W. (2020). Studi literatur pendekatan pembelajaran STEAM menyongsong era society 5.0. *Prosiding Seminar Dan Diskusi Pendidikan Dasar*, 50–58. https://journal.unj.ac.id/unj/index.php/psdpd/article/view/17767

Yusliani, E., Burhan, H. L., & Nafsih, N. Z. (2019). Analisis Integrasi Keterampilan Abad Ke-21 Dalam Sajian Buku Teks Fisika SMA Kelas XII Semester 1 [Analysis of the Integration of 21st Century Skills in Class XII Semester 1 High School Physics Textbooks]. *Jurnal Eksakta Pendidikan (JEP)*, *2*(3), 184–191. https://doi.org/10.24036/jep/vol3-iss2/392

Appendices

1. Students' worksheet

1) PROJECT TITLE
………

2) PURPOSE
………

3) PROBLEM FORMULATION
………

4) TOOLS AND MATERIALS
………

5) STEP WORK
………

6) ACTIVITY SCHEDULE
………

7) ETHNOECOLOGY-CAL STEAM INTEGRATED PROJECT DESCRIPTION
………

8) LITERATURE REVIEW RESULTS
………

9) PROJECT DESIGN DRAFT
………

10) PROJECT TRIAL
………

11) CONCLUSION
………

2. Video project

3. Project result